

AUTOMATED HUMAN AGE AT DEATH ESTIMATION SYSTEM FROM
LONG BONES HISTOLOGY

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This humble work is dedicated to my beloved mother who taught me to accomplish through patience, determination and faith, my father, my sisters and brothers. Their love, prayers, support and motivation always inspire me to achieve my goals.



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ABSTRACT

Human age estimation at death from bone histology is a frequent and important requirement in forensic anthropology. Usually human age at death is estimated manually from bone histology or morphology. Manual methods of age estimation from bone histology involve three main phases that includes, analysis of variations in microscopic characteristics of bone with age, developing age regression equation based on the variation analysis and estimation of age using regression equation. However manual age at death estimation is not only tedious and time consuming process but also prone to observation variability and produce subjective results. Furthermore, there exists no digital database that can store the information of bone samples of Malaysian population. Hence it is vital to develop a histological automated system for age at death estimation to eliminate the problems of manual methods. This study presents the development of automated system for human age at death estimation from bone histology. Six histological and two morphological parameters were analyzed in 44 samples of long bones (humerus, radius, ulna, tibia, fibula and femur). First, the measurements and analyses were carried out using manual methods and then an automated system was developed to eliminate the problems of the manual process. The system assists in automatic measurements and calculations of bone histological parameters, analysis of parameters with age, developing regression equation and estimation of age. The automatic system also provides a digital database capable of storing the information of all parameters. The results of the system shows that histological parameters specifically percentage area covered by Haversian canals and mean Haversian canal area possess the highest correlation with age. Morphological parameters do not show significant correlation with age in Malaysian population. Age regression equation is developed with SEE of 8.3 years. The automatic system estimates age within 10 years of the actual ages for 89% of the samples. The automatic system is evaluated by seven forensic anthropologists and is considered effortless and acceptable for automatic age at death estimation from bone histology.

ABSTRAK

Anggaran usia kematian manusia menerusi histologi tulang adalah perkara yang penting dalam antropologi forensik. Pengiraan kaedah masa kematian manusia masih menggunakan cara manual morfologi. Kaedah tersebut melibatkan tiga fasa utama yang merangkumi, analisis variasi ciri-ciri mikroskopik usia tulang, persamaan regresi umur berdasarkan analisis variasi dan anggaran umur menggunakan persamaan regresi. Walau bagaimanapun, kaedah anggaran kematian menggunakan histologi tulang adalah menjemukan dan memakan masa akan tetapi terdedah kepada kepelbagaian pemerhatian yang subjektif. Selain itu, tiada pangkalan data sistematik digital yang menyimpan maklumat sampel tulang penduduk Malaysia. Oleh itu, adalah penting untuk membangunkan suatu sistem automatik histologi untuk menganggarkan umur kematian manusia dan menghapuskan masalah kaedah manual. Kajian ini membentangkan pembangunan sistem automatik penganggarkan umur kematian manusia dari histologi tulang. Enam histologi dan dua parameter morfologi telah dianalisis menggunakan 44 sampel tulang panjang (humerus, radius, ulna, tibia, fibula dan femur). Pertama, pengukuran dan analisis telah dijalankan menggunakan kaedah manual beserta pembangunan sistem automatik. Sistem ini membantu pengiraan automatik parameter histologi tulang, analisis parameter untuk usia, persamaan regresi dan anggaran usia. Sistem automatik juga menyediakan pangkalan data digital yang mampu menyimpan maklumat semua parameter. Hasil dari sistem ini menunjukkan bahawa parameter histologi khususnya kawasan peratusan yang diliputi oleh terusan Haversian dan min kawasan Haversian memiliki korelasi tertinggi dengan parameter usia morfologi tidak menunjukkan korelasi yang ketara dengan usia penduduk Malaysia. Formula regresi umur yang dikembangkan oleh SEE adalah sebanyak 8.3 tahun. Sistem automatik menganggarkan usia dalam anggaran 10 tahun dari usia sebenar untuk 89% sampel. Sistem automatik yang telah dinilai oleh tujuh ahli antropologi forensik ialah dianggap mudah dan boleh diterima untuk anggaran usia kematian histologi tulang.

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LIST OF ABBREVIATIONS

<i>2D</i>	-	Two dimensions
<i>3D</i>	-	Three dimensions
μm	-	Micro meter
<i>mm</i>	-	Millimeter
<i>A</i>	-	Anterior
<i>AL</i>	-	Anterolateral
<i>AM</i>	-	Anteromedial
<i>BMU</i>	-	Basic multicellular unit
<i>C</i>	-	Celsius
<i>CSI</i>	-	Crime scene investigations
<i>CT</i>	-	Cortical thickness
<i>DVI</i>	-	Disaster victim identification
<i>F</i>	-	Fragments
<i>GUI</i>	-	Graphical user interface
<i>H+</i>	-	Hydrogen Ion
<i>HCA</i>	-	Haversian canal area
<i>HCD</i>	-	Haversian canal diameter
<i>HCM</i>	-	Mean Haversian canal area
<i>HCN</i>	-	Total Haversian canal number
<i>H_{par}</i>	-	Percentage Haversian canal area
<i>HCR</i>	-	Mean Haversian canal radius
<i>HLC</i>	-	Haversian lamella count
<i>HP</i>	-	Hyperparathyroidism
<i>HUKM</i>	-	Hospital University Kebangsaan Malaysia
<i>L</i>	-	Lateral
<i>M</i>	-	Medial
<i>MCD</i>	-	Medullar cavity diameter

<i>Mpfb</i>	-	Mean percent fragmental bone
<i>Mpob</i>	-	Mean percent osteonal bone
<i>Mpub</i>	-	Mean percent unremodeled bone
<i>MSE</i>	-	Mean squared error
<i>N/A</i>	-	Not attempted
<i>NH</i>	-	Non-haversian
<i>NIH</i>	-	National Institutes of Health
<i>OC</i>	-	Osteon count
<i>OD</i>	-	Osteon density
<i>OI</i>	-	Osteogenesis imperfecta
<i>OP</i>	-	Osteon population
<i>OPD</i>	-	Osteon population density
<i>p</i>	-	Significance value
<i>P</i>	-	Posterior
<i>PC</i>	-	Primary canal
<i>PL</i>	-	Posterolateral
<i>PM</i>	-	Posteromedial
<i>RAP</i>	-	Regional acceleratory phenomenon
<i>RMSE</i>	-	Root mean squared error
<i>ROI</i>	-	Region of interest
<i>RS</i>	-	Resorption spaces
<i>SEE</i>	-	Standard error of estimation
<i>SPPS</i>	-	Statistical Package for Social Sciences
<i>UKM</i>	-	University Kebangsaan Malaysia
<i>UKMMC</i>	-	University Kebangsaan Malaysia Medical Centre
<i>VIAS</i>	-	Volume Integration and Alignment System

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PERPUSTAKAAN TUNKU TUN AMINAH

CHAPTER 1

INTRODUCTION

1.1 Background

The skeleton changes across the human life span. These variations are characterized by bone formation and growth throughout childhood, followed by a gradual loss of bone density. Loss of bone density in human skeleton begins in early adulthood and can accelerate significantly in older adults. Human skeleton have the capability to store the information of these variations that can be studied and analyzed even long after their death. Human skeletal remains offer significant source of information about the identity of a body, ancestry and the cause and time of death (Hadi, Muhammad & Amber, 2018). The identification of an individual from skeletal remains makes it of particular importance in case of decomposed bodies, where it is not possible to identify the body from DNA or fingerprints. The identification of an individual from skeletal remains involve estimation of age at the time of death, identification of sex, origin and height. Estimation of age at death is one of the basic identifier to find out the true identity of an individual from a decomposed body. Human age estimation at death involves a detail study of bones or fragments of bone of an unknown decomposed body to assign a biological age to that individual.

Human age estimation at death have significant implications in physical anthropology and forensic sciences. In forensic sciences, estimating age at death is used in crime scene investigations (CSI) and disaster victim identification (DVI). In

bio archaeology it can be used for developing demographic profiles. The implications of age estimation at death also lies in paleopathology for identifying the causes and frequency of diseases, which can help in prediction of new diseases or re-emergence of old diseases.

Conventionally, age estimation techniques are based on macroscopic or morphological analysis. Morphological methods involve study of shape and structures of bones. This method focuses on length, diameter, growth, shape and fusion of human bones to identify skeletal maturity (Figure 1.1). Most of morphological age estimation methods rely on the degenerative variations that occurs at the macroscopic level of bone morphology. (Suchey, 1979; Iscan, Loth & Wright, 1984; Katz & Suchey, 1986; Brooks & Suchey, 1990)

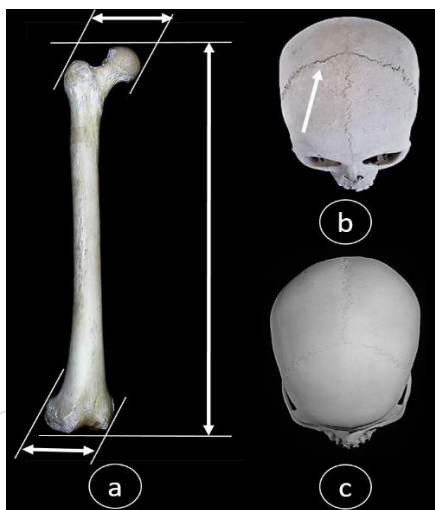


Figure 1.1: Morphological analysis to identify skeletal maturity (a) Long bone (femur) (b) Fusion of skull (c) Mature skull after fusion

Morphological methods are based on subjective assessment of different, and often subtle, stages of degeneration (Ekta, 2017). These methods are non-destructive and can usually be performed quickly, however, they require qualitative analysis that can lead to generate a significant amount of observer error. Morphological age estimation techniques based on identifying the degree of degeneration of bones are imprecise for those beyond 50 years. Moreover, morphological methods of age estimation are not useful in cases of fragmented skeletal remains often encountered in forensic sciences. Subjectivity of morphological or macroscopic observations led to

seek more objective and quantitative methods, based on histological or microscopic analysis of bones.

Histological age estimation methods involve investigation of age-associated variations in microscopic features of bones. These microscopic variations of bones take place due to the life-long metabolic process known as remodeling (Clemente & Miguel, 2018). In these methods observable microscopic features (microstructures) of bones are measured and quantified. These methods are based on the fact that continuous growth and turnover of bones produces distinctive computable microstructures that persist long after their formation. These microstructures are known as osteons or Haversian systems (Figure 1.2), (Stout, 1986; Dudar, Pfeiffer & Saunders, 1993).

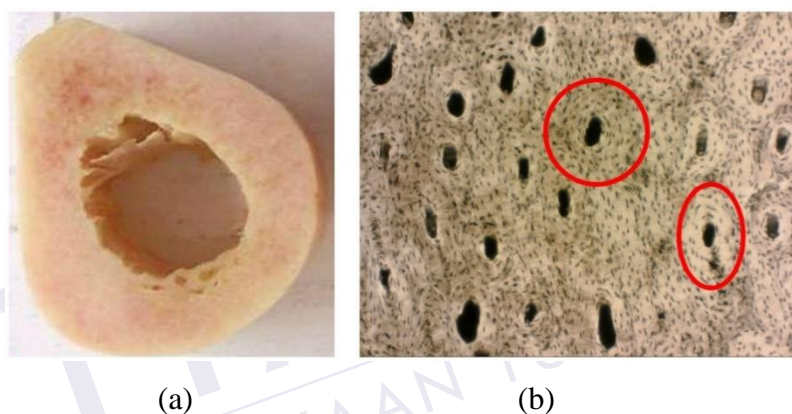


Figure 1. 2: (a) Fragment of femur (b) Microscopic view of femur (Haversian system in red circles)

Histological age estimation methods are advantageous, where the morphology of the skeleton is altered to the degree that morphological methods are no longer applicable, for example, in cases of burned or fragmentary skeletons. Histological methods offer to estimate the age of individuals above 50 years (Ericksen, 1991).

Several methods of age at death estimation from bone histology have been proposed over the years. In these methods age at death have been estimated using skull, ossification centers, dental eruption, epiphyseal closure, length of the long bones and the vertebral column (Cardoso & Rios, 2011; Faridah, Robert & Holger, 2013; Gupta, Kaur, Jawanda & Sahi, 2014; Sinthubua, Theera, Ruengdit & Mahakkanukrauh, 2016; Kacar, Unlu, Beker & Balcik, 2017).

The accuracy of existing histological age estimation methods diverge from each other due to the number and location of samples, bone type, observed microscopic features and amount of fragmented bone required (Katzenberg, 2000). Furthermore, the accuracy of these age estimation methods is dependent on the diagnosis of several age related changes in skeleton that occur during the life span. Different factors such as intrinsic and extrinsic genetic factors, environmental and biomechanical factors alters the histology of the skeleton (Faridah *et al.*, 2013). Occupation and different physical activity could also lead to distinct bone mass. Factors such as gender, hormones, disease, diet, life history, ethnicity, nutritional stress and length of daylight influence the rate at which a person's skeleton breaks down (Frame, 1971; Thompson, 1979; Richman, Ortner & Schulter, 1979; Thompson & Gunness, 1981).

Bones with different size of osteons and haversian canals exhibits different osteon population densities and will reach to asymptotes at different stages of age (Pfeiffer, Crowder, Harrington & Brown, 2006). Bone microstructures were also identified to have difference with population and ancestry (Cho, Stout, Madsen & Streeter, 2002; Pfeiffer *et al.*, 2006). As bone microstructures show different patterns at same age in two different population due to under or over ageing, it is vital in classifying the reliability of age estimation techniques to consider the variation of bone microstructures with population. Hence, the accuracy of age estimation methods developed on the samples of one population might not be reliable for another population.

Histological age estimation techniques provided relatively accurate results in American and European populations. However, age at death estimation in Malaysian population are mostly based on morphological methods and has not been much benefited from histological age estimation techniques. Histological techniques for age estimation has been addressed by very limited researchers in Malaysian population. Most noticeable histological study for age estimation in Malaysian population is published in 2014 with accuracy of ± 10.9 years (Faridah *et al.*, 2013). This method was based on manual observation of bone microstructures. Even though histological methods of age estimation has been proven beneficial over morphological methods, yet manual observation of bone microstructures is a time consuming process and can lead to increase the observer error. These limitations could be reduced by automating the process of observation and computation with the help of digital equipment and computer algorithms. This study is dedicated to investigate the characteristics of

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